

Photodiodes Temperature Characterization

1. Test Description and Objectives

The main objective of this test is to characterise the temperature behaviour of the photodiode and calibrate its results.

2. Test Set-Up

- ADCS board and the PocketQube lateral boards.
- Multimeter, alligator clips ,cables and jumpers for the connection between the photodiodes and the ADCS board.
- A computer.
- Black coated box.
- An halogen bulb with its correct power source.
- Hair dryer.

3. Test Plan

Following the Shockley Diode equation, the current coming out the photodiode depends of the temperature, following an exponential function.

The Shockley diode equation is the following one:

$$I_D = I_{SAT(T)} \left(e^{\frac{V_D}{V_T}} - 1 \right)$$

Where:

I_D is the diode current.

$I_{\text{sat}}(T)$ is the reverse bias saturation current.

V_D is the voltage of the diode.

V_T is the thermal voltage.

μ is the ideality factor, it will be assumed that it is equal to 1.

In this equation there are two key parameters, the V_T and the $I_{\text{sat}}(T)$ which are computed with the following formulas:

$$V_T = \frac{k \cdot T}{q}$$

Where:

k is the Boltzmann constant in [J/k].

T is the temperature of the diode in kelvins.

q is the elementary charge.

$$I_{\text{SAT}}(T) = I_{\text{SAT}}(T_{\text{nom}}) \cdot \left[\left(\frac{T}{T_{\text{nom}}} \right)^3 \cdot e^{\frac{E_g}{k} \cdot \left(\frac{1}{T_{\text{nom}}} - \frac{1}{T} \right)} \right]$$

Where:

T_{nom} is the temperature in which the photodiode's characteristics are specified in the datasheet.

E_g is the energy gap.

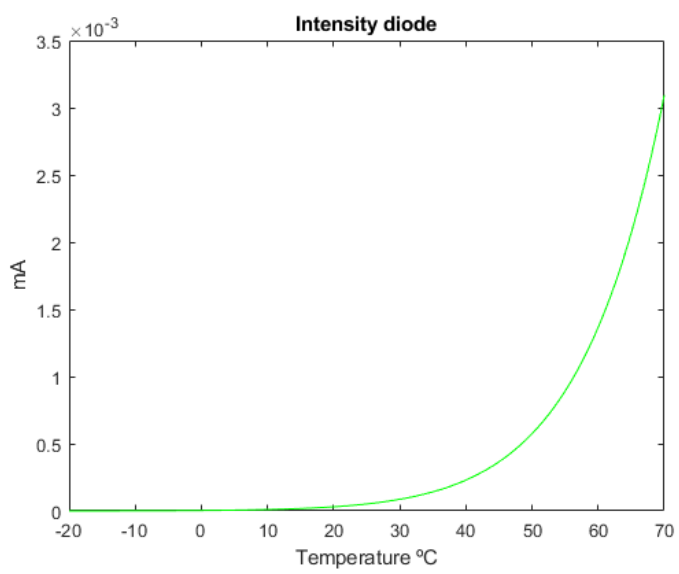
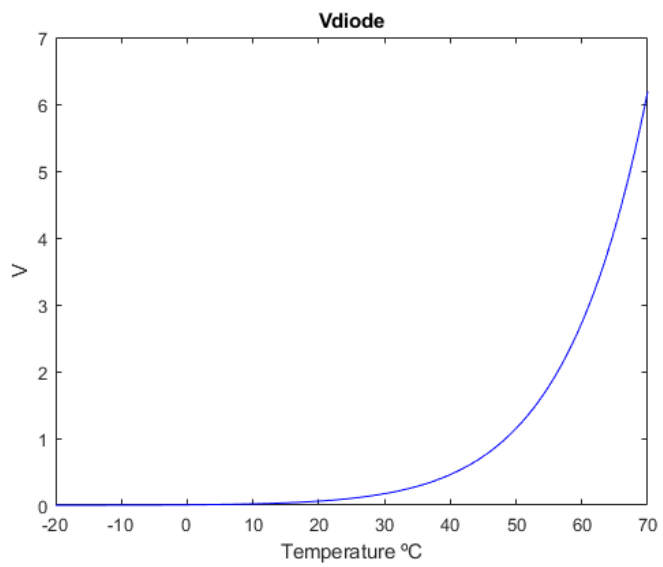
k is the Boltzmann constant in [eV/K].

$I_{\text{sat}}(T_{\text{nom}})$ is the reverse bias saturation current at the nominal temperature.

It is important to note that since the measured current of the photodiode is converted into voltage, the readings from the analog-to-digital converters will be expressed in volts. The conversion formula is as follows:

$$V_{\text{reading}} = R * I_D$$

Using this equation, the I_D and the V_D of the photodiode in function of the temperature will have this shape:



Now the next step is to derive the sensitivity equation. To obtain it, you will have to derivate the Shockley diode equation in function of the temperature:

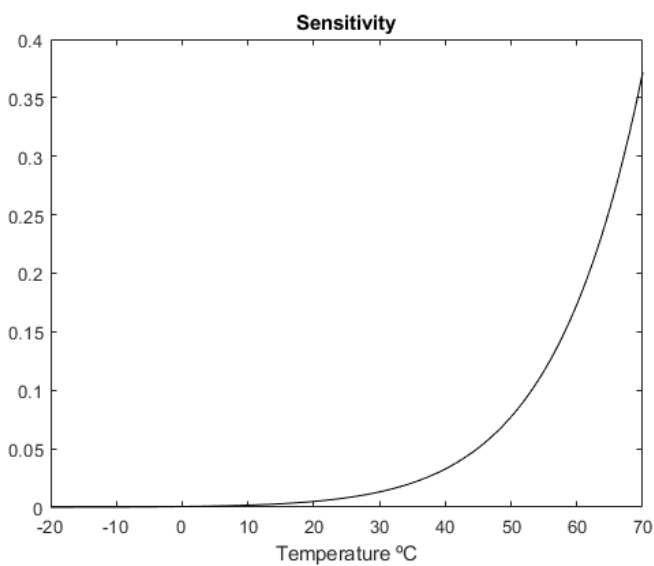
$$g(T) = \left(\frac{T}{T_{nom}}\right)^3$$

$$f(T) = e^{\frac{E_g}{k} \cdot \left(\frac{1}{T_{nom}} - \frac{1}{T}\right)}$$

$$h(T) = \left(e^{\frac{V_D \cdot q}{\mu \cdot k \cdot T}} - 1\right)$$

$$Sensitivity = R \cdot I_{sat}(T_{nom}) \cdot (g'(T) \cdot f(T) \cdot h(T) + g(T) \cdot f'(T) \cdot h(T) + g(T) \cdot f(T) \cdot h'(T))$$

The sensitivity in function of the temperature will have this shape:



All the parameters that has been obtained are the following:

Computed $I_{sat}(T_{nom})$	Measured voltage quantized values	Measured T
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At this part of the calibration the following steps have to be followed:

1. First of all, the $I_{sat}(T_{nom})$ has to be computed. In order to do that, you have to measure the I_d and V_d of the photodiode while using a constant source of light. Afterwards, isolate the $I_{sat}(T_{nom})$ from the Shockley diode equation and compute it.
2. Afterwards, put the photodiode inside the black coated box pointing towards an halogen lamp bulb. You have to take measurements of the photodiode and its operating temperature. Place the box in a place where it can reach as low temperatures as you can.

While the photodiode is taking measurements, the halogen lamp will increment the temperature inside the black coated box. The temperature will increase until a maximum point, then is the turn of the dryer, start increasing the temperature inside the box pinroducing hot air little by little.

3. Once the measurements are completed, the real voltage measured in the ADC can be computed, knowing that a 12-bit quantization is used.

$$V_D = \left(\frac{ADC \text{ Voltage}}{2^{bits} - 1} \right) \cdot V_{ref} = \left(\frac{ADC \text{ Voltage}}{2^{12} - 1} \right) \cdot 5$$

4. Next, compute the current I_{D_dId} , considering that a resistor of 20 k Ω is being used.

$$V_{reading} = R \cdot I_D \rightarrow I_D = \frac{V_{reading}}{R}$$

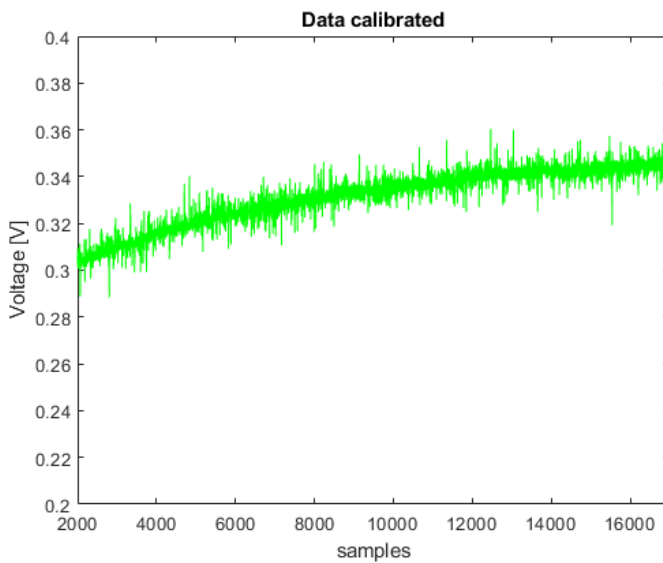
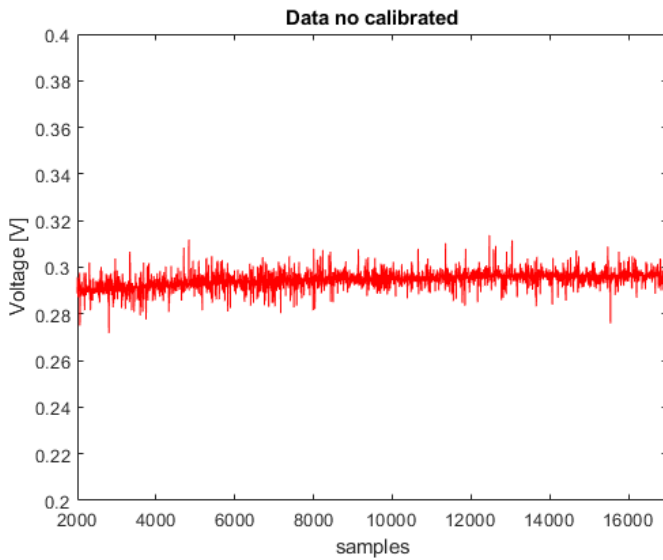
5. Later, compute the **Vd** isolating it from the **Id** equation:

$$V_D = \eta V_T \ln \left(\frac{I_D}{I_{SAT(T)}} + 1 \right) \approx \frac{kT}{q} \ln \left(\frac{I_D}{I_{SAT(T)}} \right)$$

6. Afterwards, compute the sensitivity for each measurement using the sensivity equation. The V_d and the temperature will be different for each measurement.
7. The last step is to calibrate the measurements using the following equation:

$$Data \text{ calibrated} = (1 + Sensitivity) \cdot R \cdot I_D$$

4. Test Results



A simulation was conducted with a total of 17,000 samples of photodiode measurements taken at temperatures ranging from 15 to 35 degrees Celsius. As shown in the calibrated data, photodiode measurements increase with rising temperatures.

5. Conclusions

The calibration test has been conducted successfully.

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